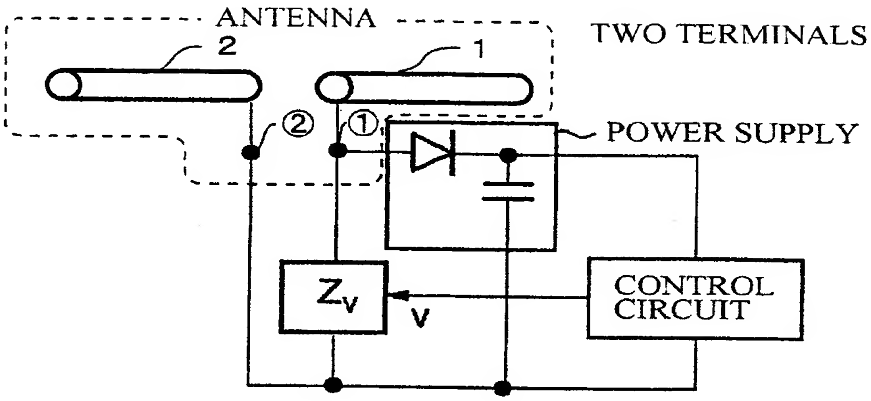
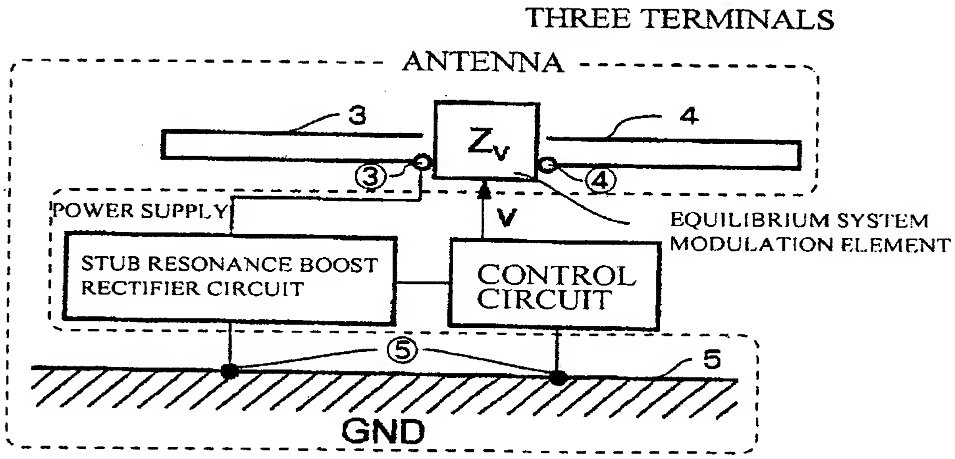
FIG.1



PRIOR ART

FIG.2


THREE TERMINALS
ANTENNA
3
4
$Z_V$
③
④
V
EQUILIBRIUM SYSTEM MODULATION ELEMENT
POWER SUPPLY
STUB RESONANCE BOOST RECTIFIER CIRCUIT
CONTROL CIRCUIT
⑤
5
GND

PRESENT INVENTION

FIG. 3

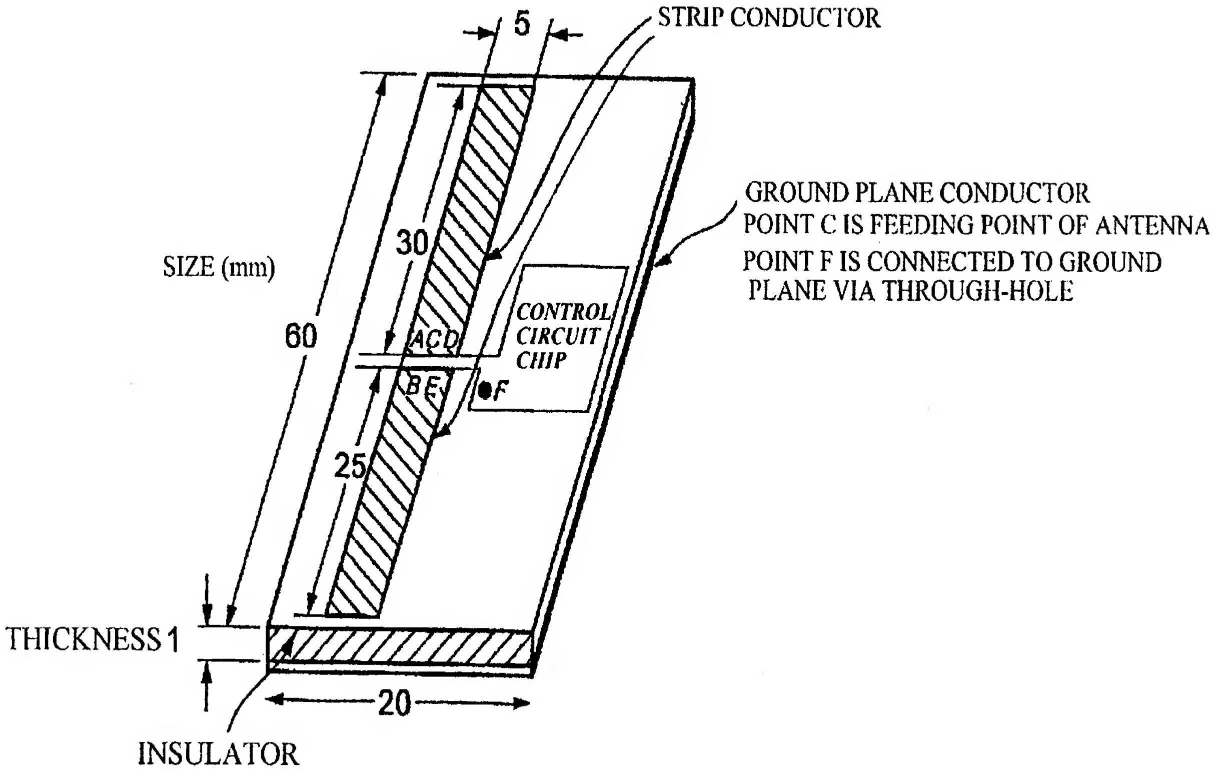

5
STRIP CONDUCTOR
GROUND PLANE CONDUCTOR
POINT C IS FEEDING POINT OF ANTENNA
POINT F IS CONNECTED TO GROUND
PLANE VIA THROUGH-HOLE
SIZE (mm)
30
60
ACD
BE
CONTROL
CIRCUIT
CHIP
F
25
THICKNESS 1
20
INSULATOR

FIG. 4

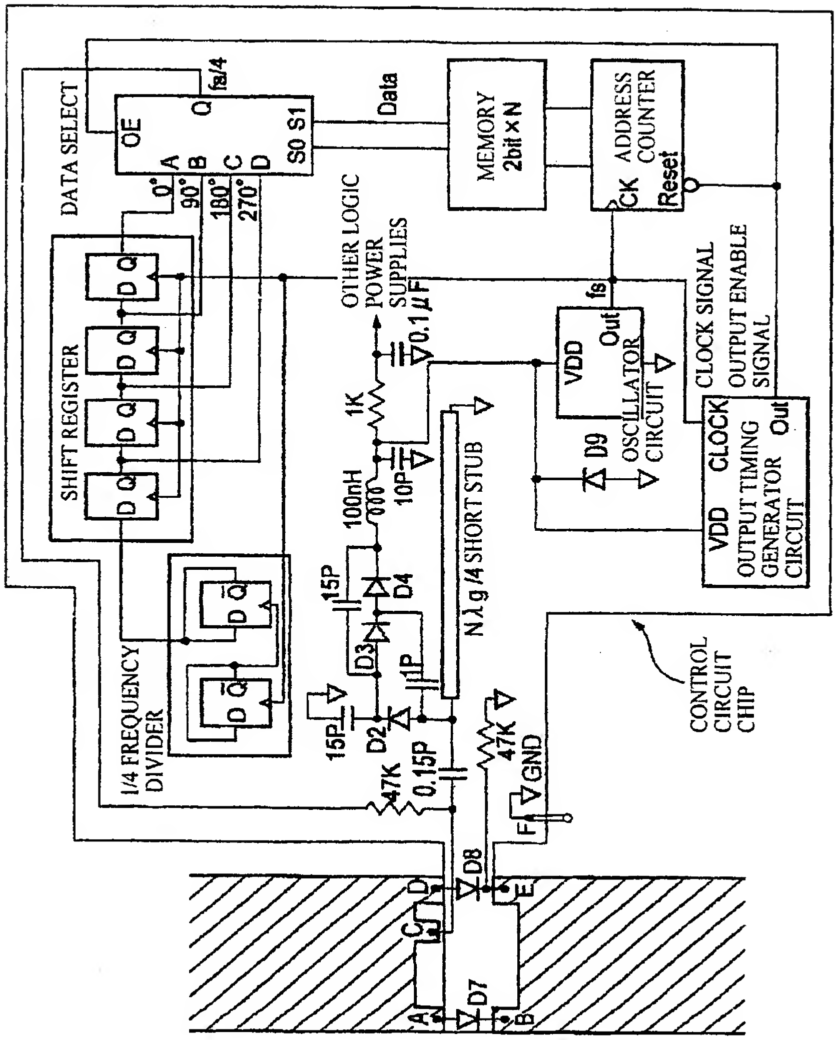
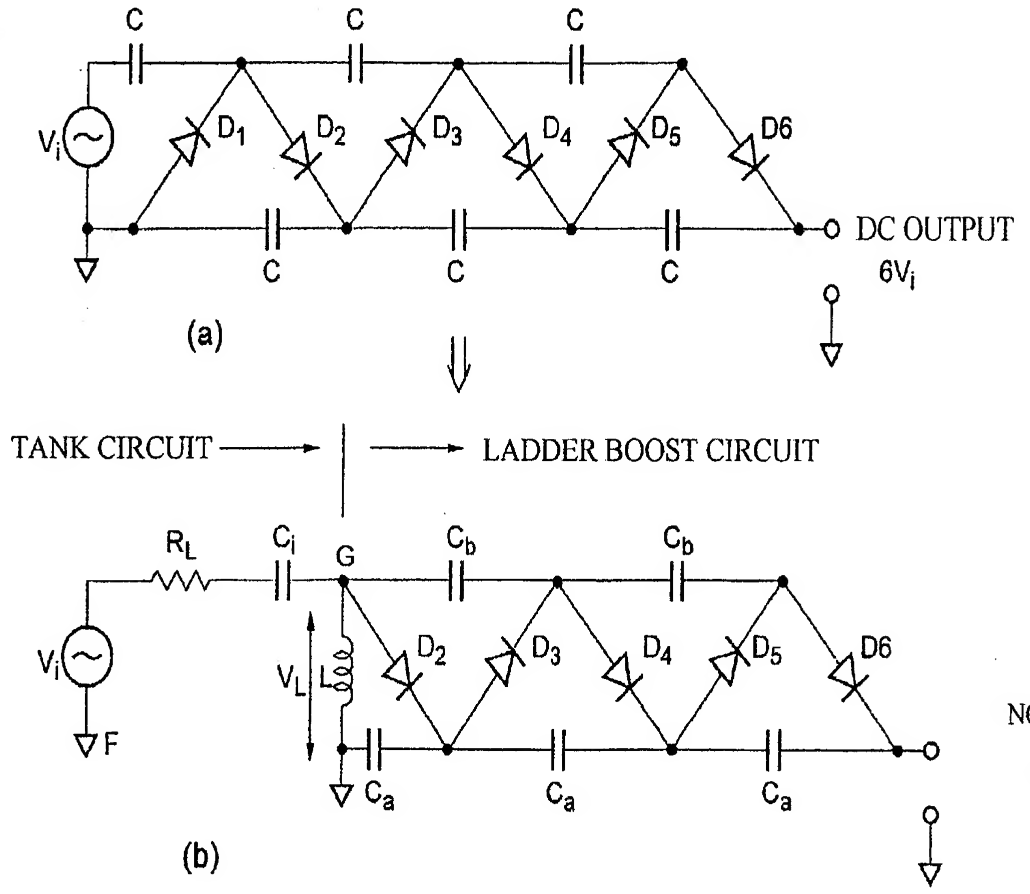

DATA SELECT
OE
Q
fs/4
A
B
C
D
S0 S1
0°
90°
180°
270°
Data
MEMORY
2bit × N
ADDRESS
COUNTER
CK
Reset
SHIFT REGISTER
D Q
D Q
D Q
D Q
OTHER LOGIC
POWER
SUPPLIES
0.1 μF
1K
VDD
Out
fs
OSCILLATOR
CIRCUIT
CLOCK SIGNAL
OUTPUT ENABLE
SIGNAL
D9
VDD
CLOCK
Out
OUTPUT TIMING
GENERATOR
CIRCUIT
100nH
10P
15P
D4
D3
1P
Nλg /4 SHORT STUB
1/4 FREQUENCY
DIVIDER
D Q̄
D Q̄
15P
D2
47K
0.15P
47K
GND
F
CONTROL
CIRCUIT
CHIP
D8
A
C
D
D7
B
E

FIG. 5

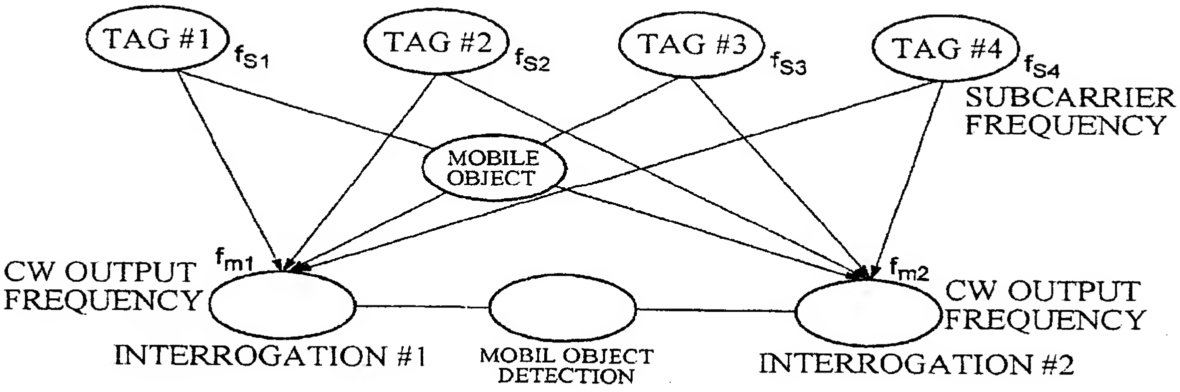


NOTE THAT $C_a >> C_b$

DC OUTPUT $\frac{5V_i}{R_L W_0 C_i}$

$W_0$ IS RESONANCE
ANGULAR FREQUENCY
OF TANK CIRCUIT

FIG.6



PRESENCE OR ABSENCE OF TAG RESPONSE SIGNAL

| | | TAG NUMBER | | | |
|---|---|---|---|---|---|
| | | #1 | #2 | #3 | #4 |
| INTERROGATION NUMBER | #1 | ○ | ○ | × | ○ |
| | #2 | × | ○ | ○ | ○ |

FIG.7

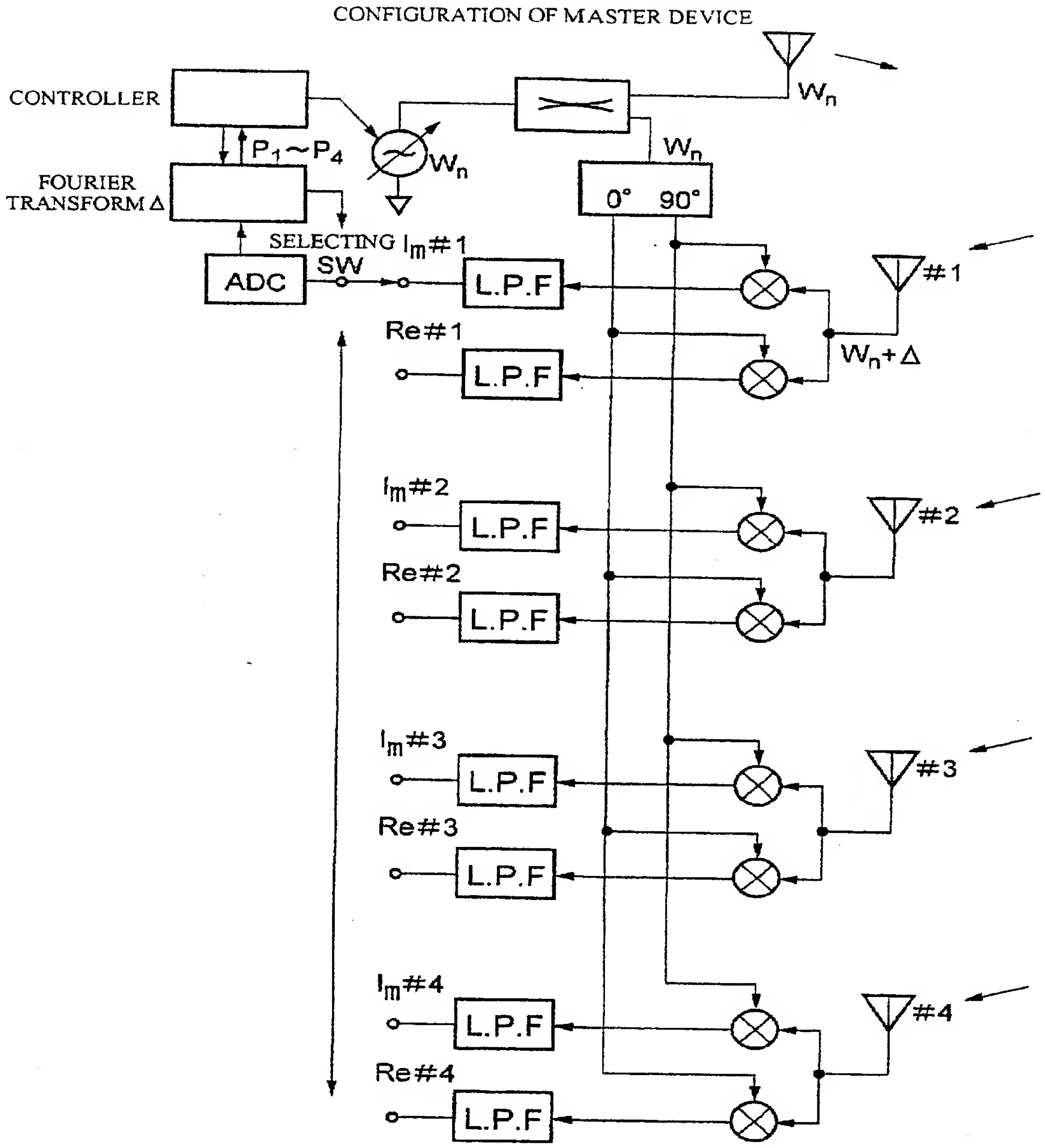

CONFIGURATION OF MASTER DEVICE
CONTROLLER
$P_1 \sim P_4$
FOURIER TRANSFORM Δ
$W_n$
$W_n$
$W_n$
0°
90°
SELECTING SW
ADC
$I_m$#1
L.P.F
Re#1
L.P.F
#1
$W_n+\Delta$
$I_m$#2
L.P.F
Re#2
L.P.F
#2
$I_m$#3
L.P.F
Re#3
L.P.F
#3
$I_m$#4
L.P.F
Re#4
L.P.F
#4

FIG.8

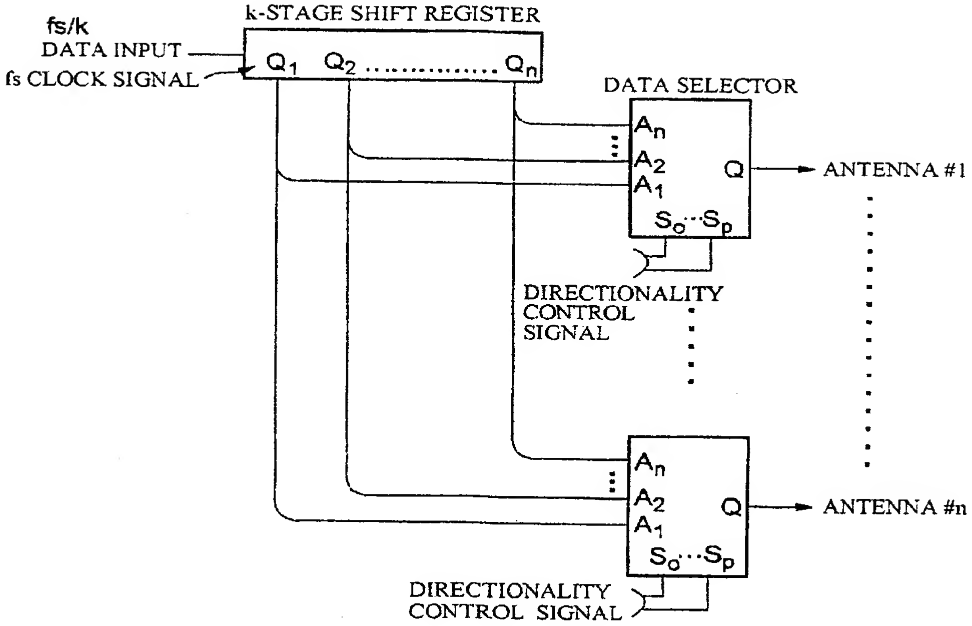

k-STAGE SHIFT REGISTER
fs/k
DATA INPUT
fs CLOCK SIGNAL
$Q_1$
$Q_2$
$Q_n$
DATA SELECTOR
$A_n$
$A_2$
$A_1$
Q
$S_o \cdots S_p$
ANTENNA #1
DIRECTIONALITY CONTROL SIGNAL
$A_n$
$A_2$
$A_1$
Q
$S_o \cdots S_p$
ANTENNA #n
DIRECTIONALITY CONTROL SIGNAL

FIG.9

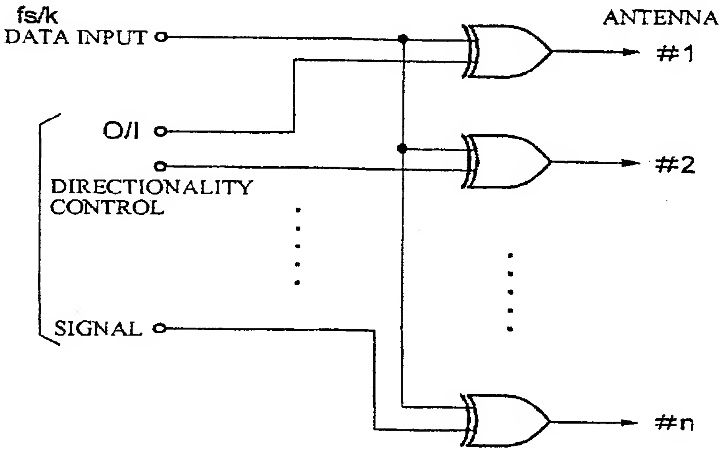

fs/k
DATA INPUT
ANTENNA
#1
O/I
#2
DIRECTIONALITY CONTROL
SIGNAL
#n

FIG. 10

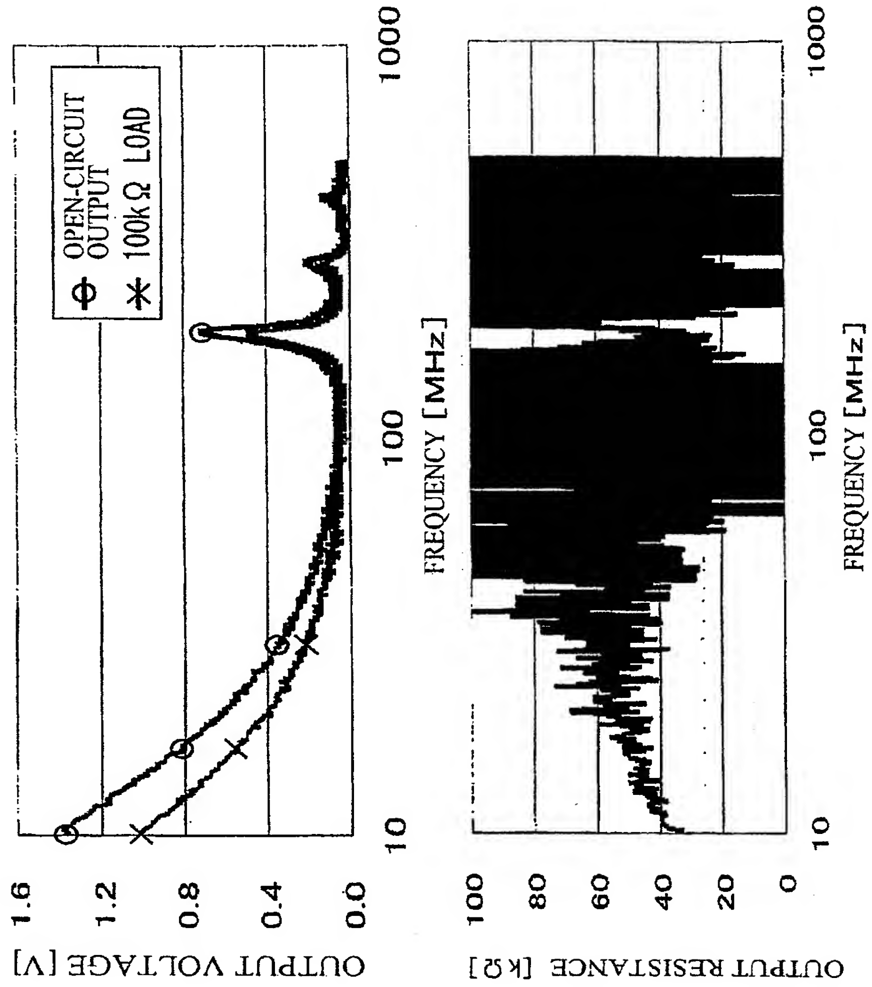

OUTPUT VOLTAGE [V]
1.6
1.2
0.8
0.4
0.0
OPEN-CIRCUIT OUTPUT
100kΩ LOAD
10
100
1000
FREQUENCY [MHz]
OUTPUT RESISTANCE [kΩ]
100
80
60
40
20
0
10
100
1000
FREQUENCY [MHz]

FIG. 11

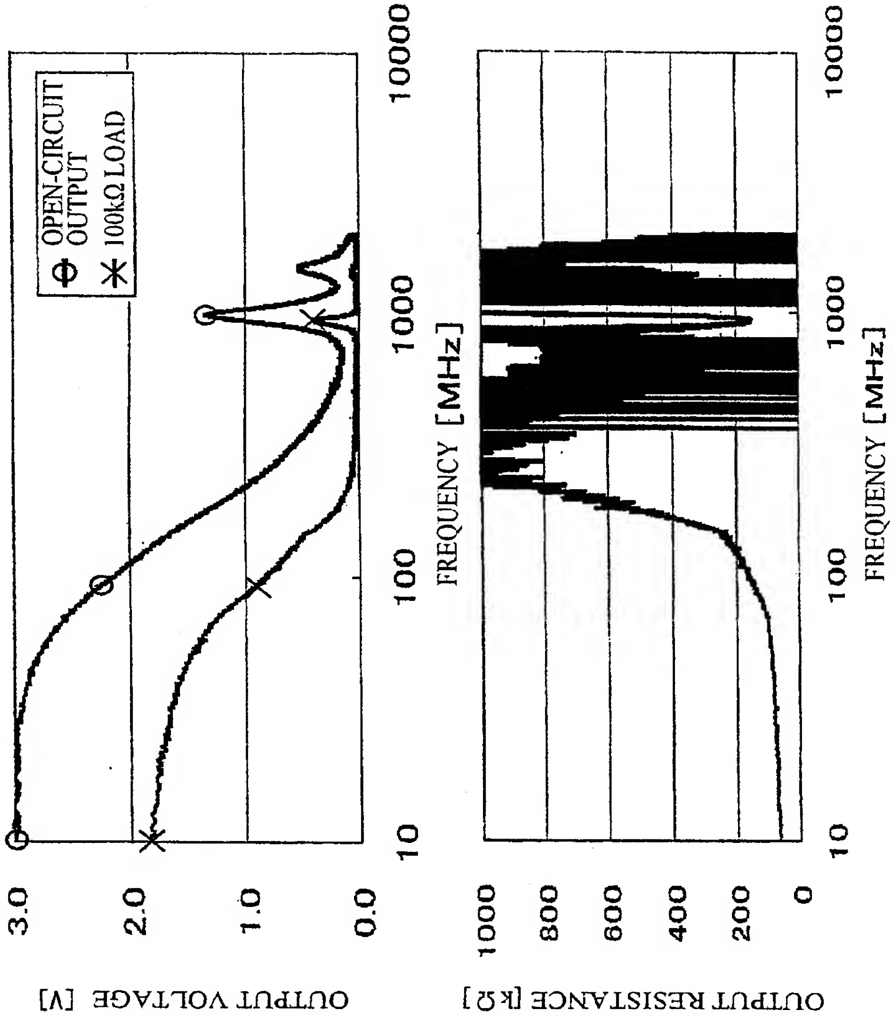

OUTPUT VOLTAGE [V]
3.0
2.0
1.0
0.0
OPEN-CIRCUIT OUTPUT
100kΩ LOAD
10
100
1000
10000
FREQUENCY [MHz]
OUTPUT RESISTANCE [kΩ]
1000
800
600
400
200
0
10
100
1000
10000
FREQUENCY [MHz]

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FIG. 12

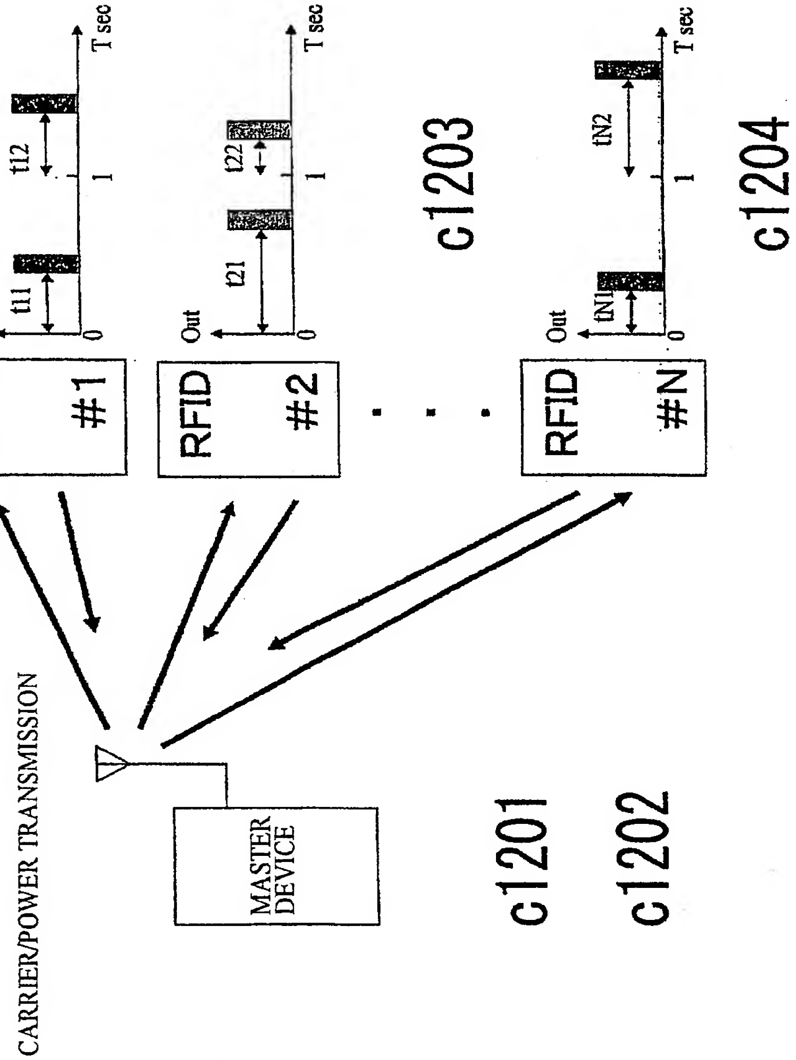

FIG. 13

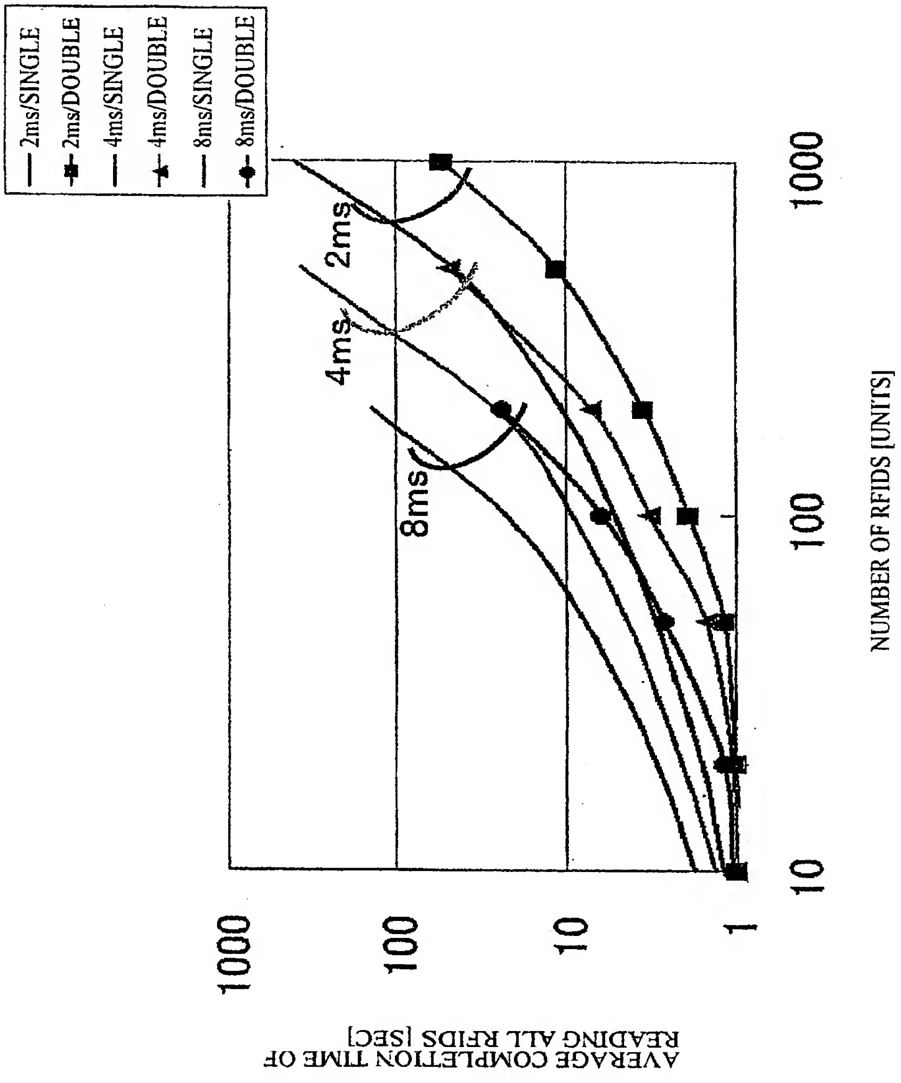
2ms/SINGLE
2ms/DOUBLE
4ms/SINGLE
4ms/DOUBLE
8ms/SINGLE
8ms/DOUBLE
2ms
4ms
8ms
1000
100
10
1
10
100
1000
NUMBER OF RFIDS [UNITS]
AVERAGE COMPLETION TIME OF READING ALL RFIDS [SEC]

FIG. 14

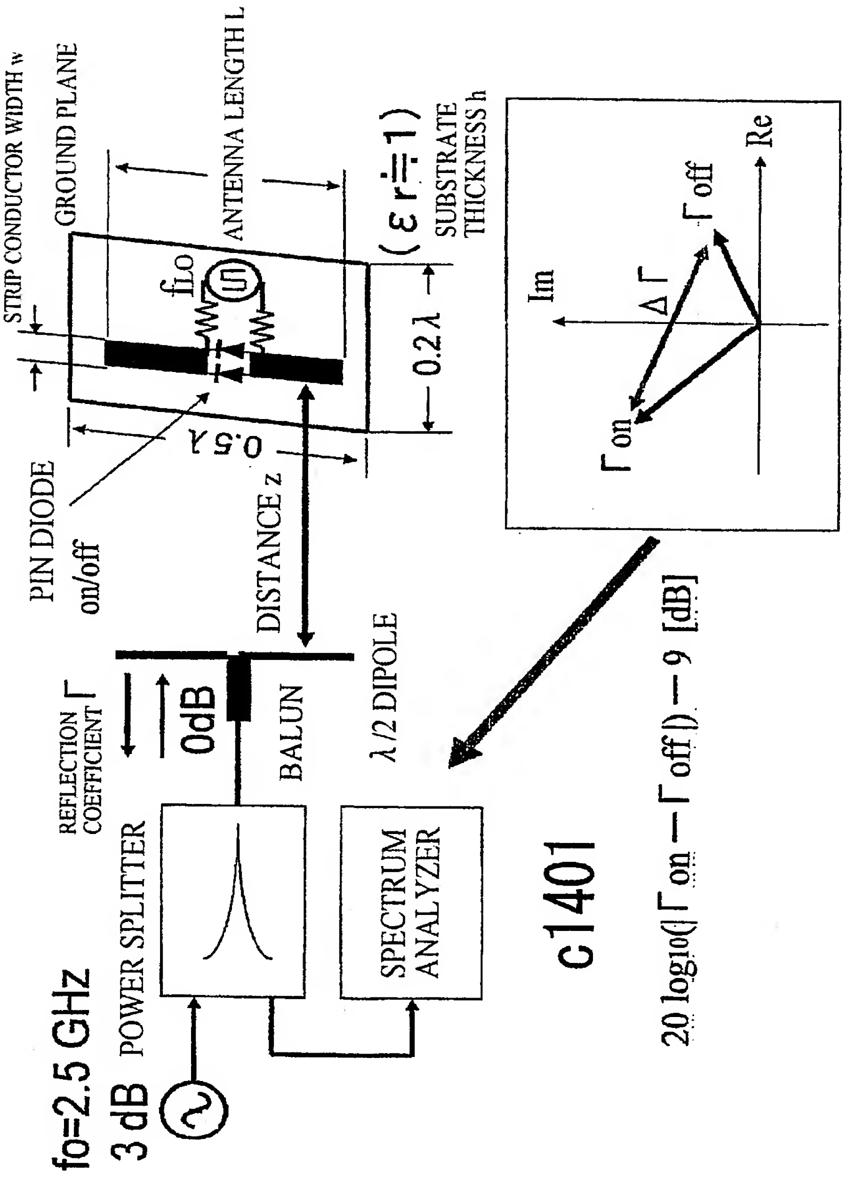
fo=2.5 GHz
3 dB
POWER SPLITTER
SPECTRUM ANALYZER
REFLECTION COEFFICIENT Γ
0dB
BALUN
λ/2 DIPOLE
DISTANCE z
PIN DIODE on/off
0.5λ
0.2λ
STRIP CONDUCTOR WIDTH w
GROUND PLANE
$f_{LO}$
ANTENNA LENGTH L
(εr≒1)
SUBSTRATE THICKNESS h
Im
Re
ΔΓ
Γoff
Γon
c1401
$20\log_{10}(|\Gamma_{on} - \Gamma_{off}|) - 9$ [dB]

FIG. 15

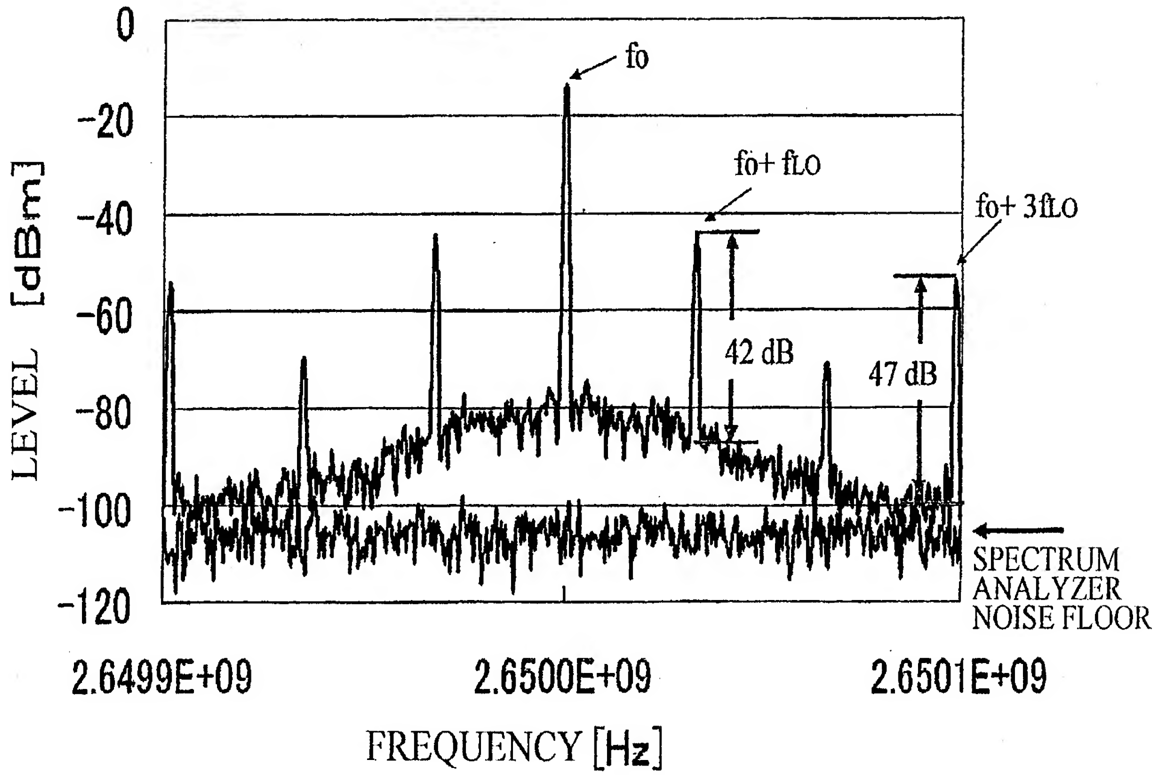
fo
fo+ fLO
fo+ 3fLO
42 dB
47 dB
0
-20
-40
-60
-80
-100
-120
LEVEL [dBm]
SPECTRUM
ANALYZER
NOISE FLOOR
2.6499E+09
2.6500E+09
2.6501E+09
FREQUENCY [Hz]

FIG. 16

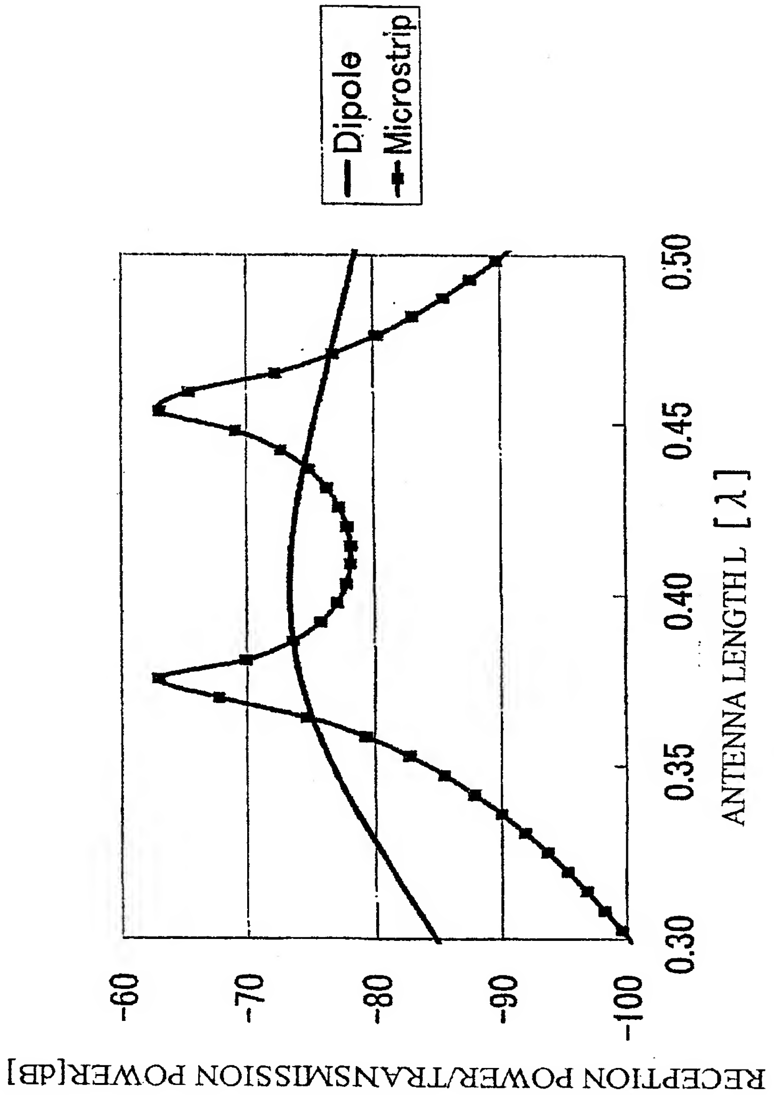
Dipole
Microstrip
-60
-70
-80
-90
-100
RECEPTION POWER/TRANSMISSION POWER[dB]
0.30
0.35
0.40
0.45
0.50
ANTENNA LENGTH L [λ]

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FIG. 17

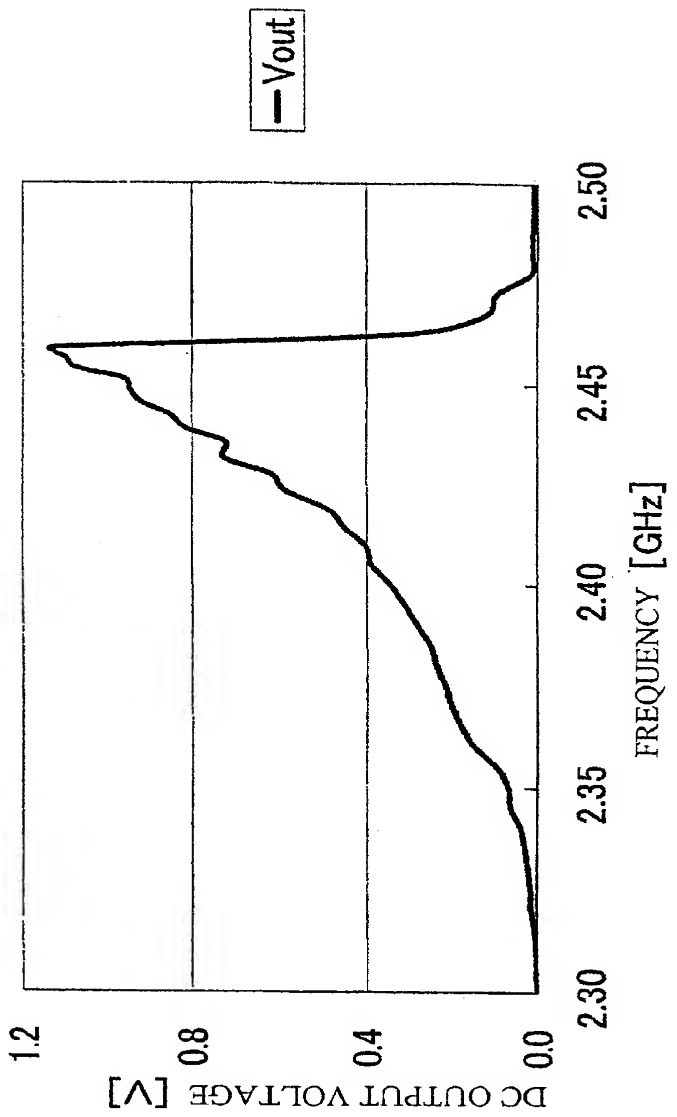

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FIG. 18

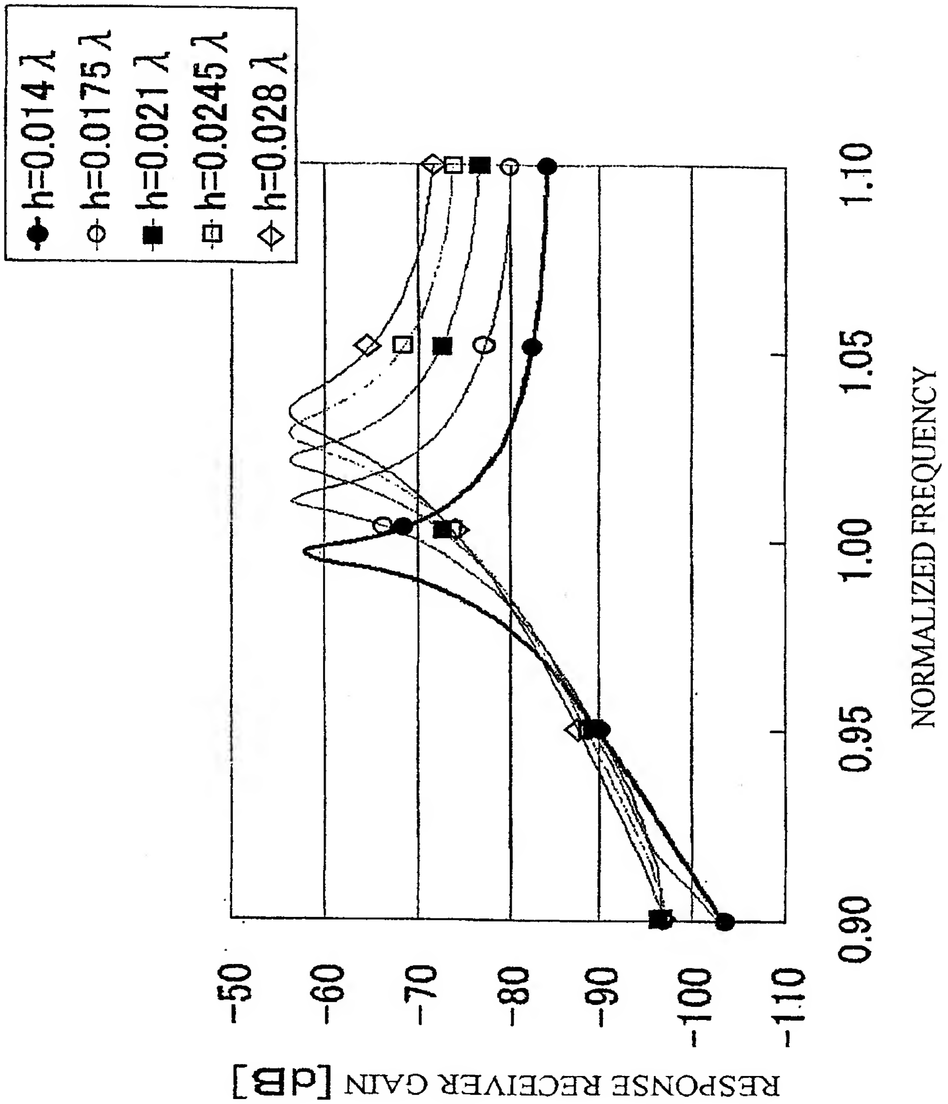


FIG. 19

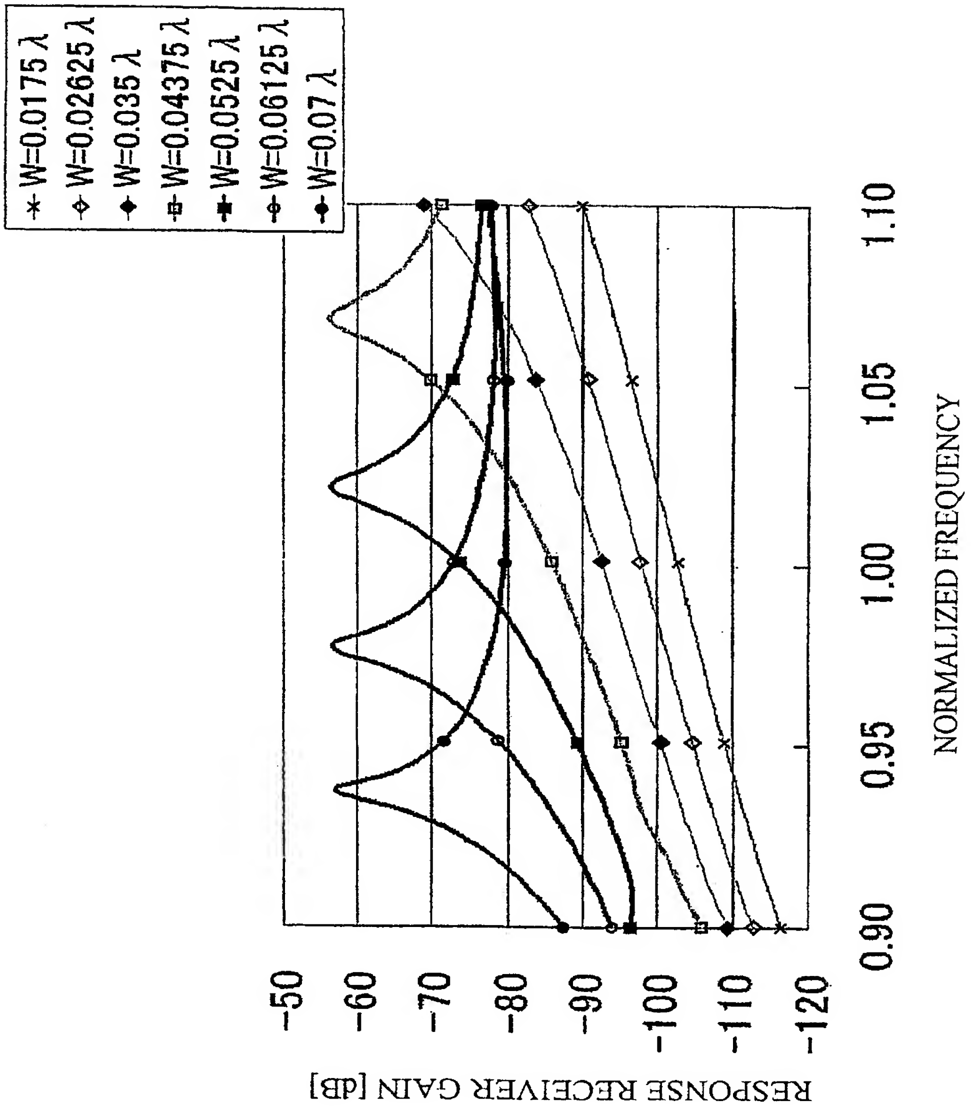

W=0.0175 λ
W=0.02625 λ
W=0.035 λ
W=0.04375 λ
W=0.0525 λ
W=0.06125 λ
W=0.07 λ
RESPONSE RECEIVER GAIN [dB]
-50
-60
-70
-80
-90
-100
-110
-120
0.90
0.95
1.00
1.05
1.10
NORMALIZED FREQUENCY

FIG. 20

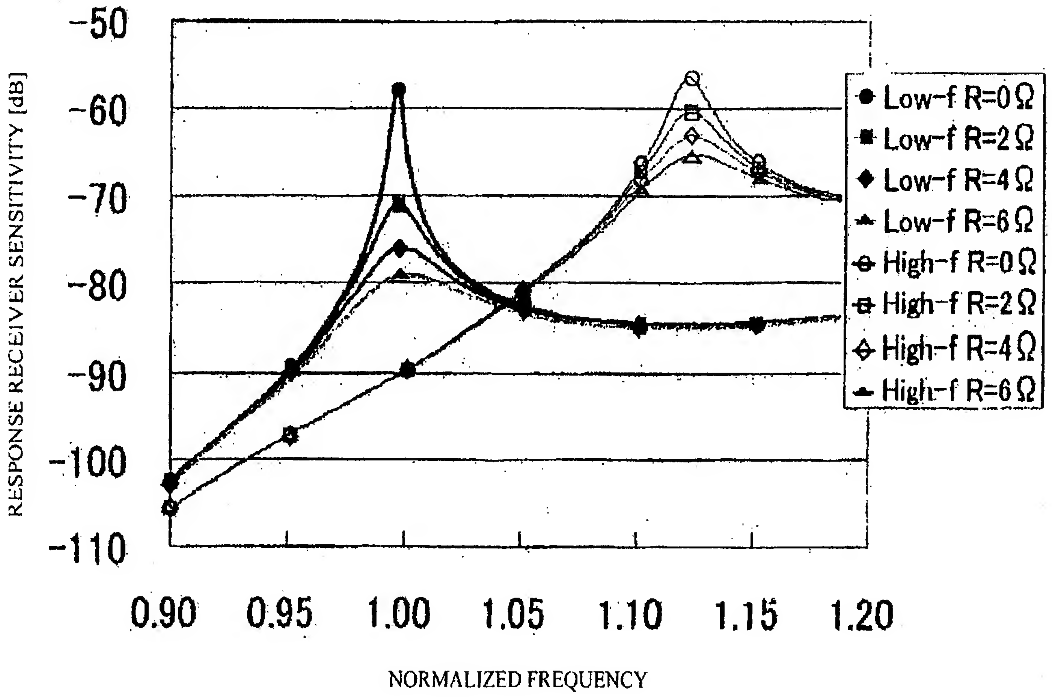

RESPONSE RECEIVER SENSITIVITY [dB]
-50
-60
-70
-80
-90
-100
-110
0.90
0.95
1.00
1.05
1.10
1.15
1.20
NORMALIZED FREQUENCY
● Low-f R=0Ω
■ Low-f R=2Ω
◆ Low-f R=4Ω
▲ Low-f R=6Ω
○ High-f R=0Ω
□ High-f R=2Ω
◇ High-f R=4Ω
△ High-f R=6Ω

FIG. 21

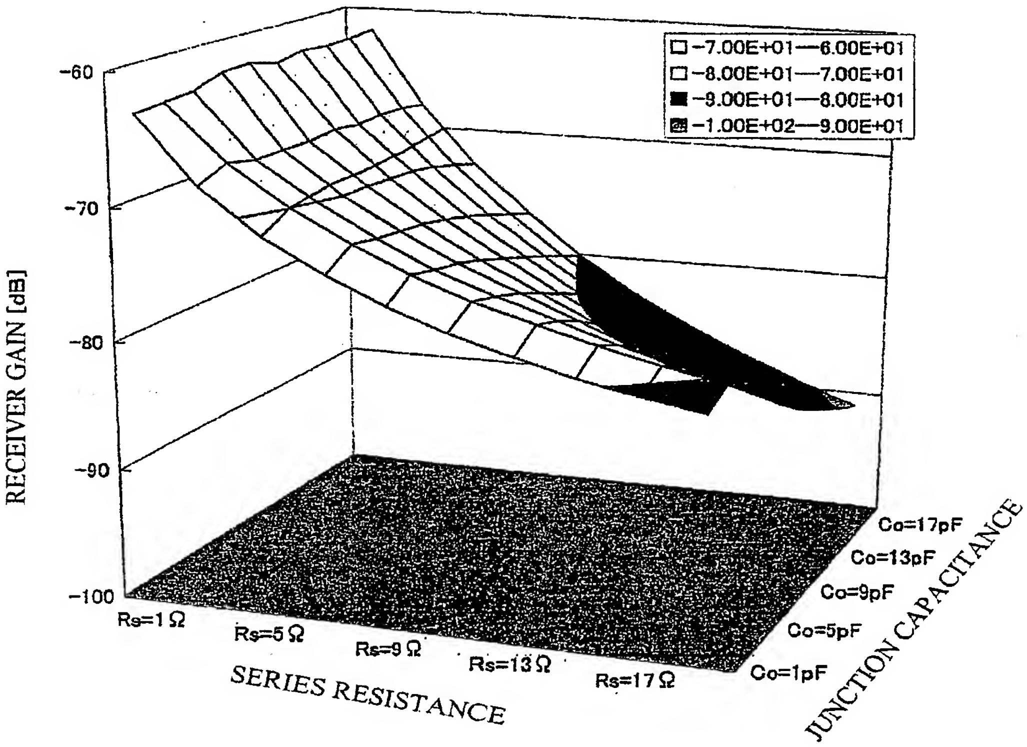
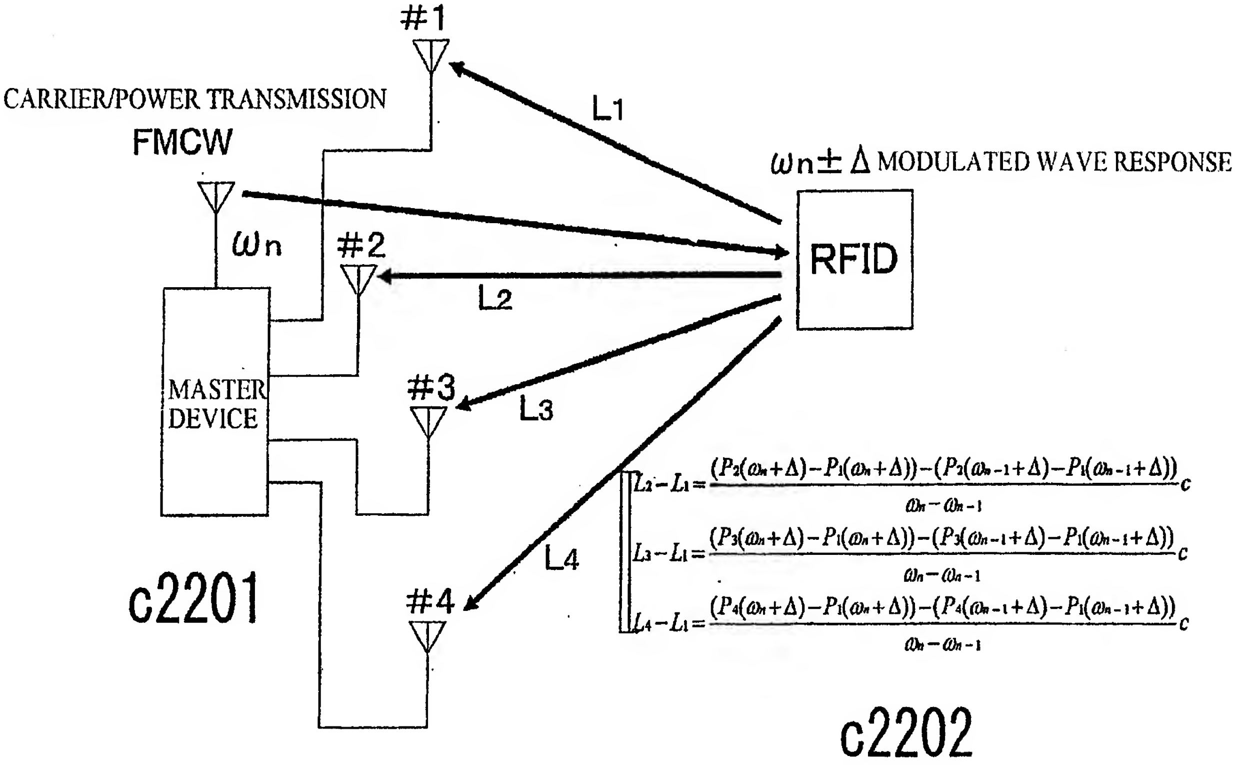

□ -7.00E+01—-6.00E+01
□ -8.00E+01—-7.00E+01
■ -9.00E+01—-8.00E+01
▨ -1.00E+02—-9.00E+01
-60
-70
-80
-90
-100
RECEIVER GAIN [dB]
Rs=1 Ω
Rs=5 Ω
Rs=9 Ω
Rs=13 Ω
Rs=17 Ω
SERIES RESISTANCE
Co=1pF
Co=5pF
Co=9pF
Co=13pF
Co=17pF
JUNCTION CAPACITANCE

FIG. 22



$$L_2-L_1=\frac{(P_2(\omega_n+\Delta)-P_1(\omega_n+\Delta))-(P_2(\omega_{n-1}+\Delta)-P_1(\omega_{n-1}+\Delta))}{\omega_n-\omega_{n-1}}c$$

$$L_3-L_1=\frac{(P_3(\omega_n+\Delta)-P_1(\omega_n+\Delta))-(P_3(\omega_{n-1}+\Delta)-P_1(\omega_{n-1}+\Delta))}{\omega_n-\omega_{n-1}}c$$

$$L_4-L_1=\frac{(P_4(\omega_n+\Delta)-P_1(\omega_n+\Delta))-(P_4(\omega_{n-1}+\Delta)-P_1(\omega_{n-1}+\Delta))}{\omega_n-\omega_{n-1}}c$$

FIG. 23

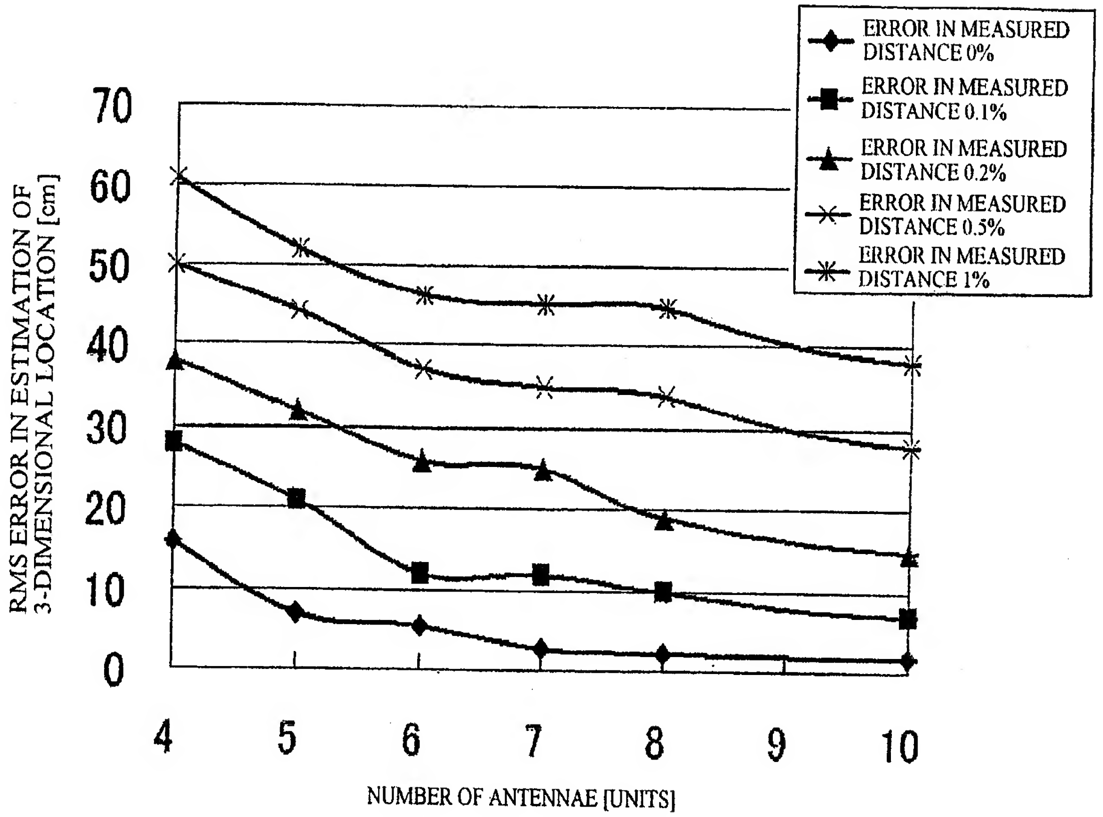

ERROR IN MEASURED DISTANCE 0%
ERROR IN MEASURED DISTANCE 0.1%
ERROR IN MEASURED DISTANCE 0.2%
ERROR IN MEASURED DISTANCE 0.5%
ERROR IN MEASURED DISTANCE 1%
RMS ERROR IN ESTIMATION OF 3-DIMENSIONAL LOCATION [cm]
70
60
50
40
30
20
10
0
4
5
6
7
8
9
10
NUMBER OF ANTENNAE [UNITS]

FIG. 24

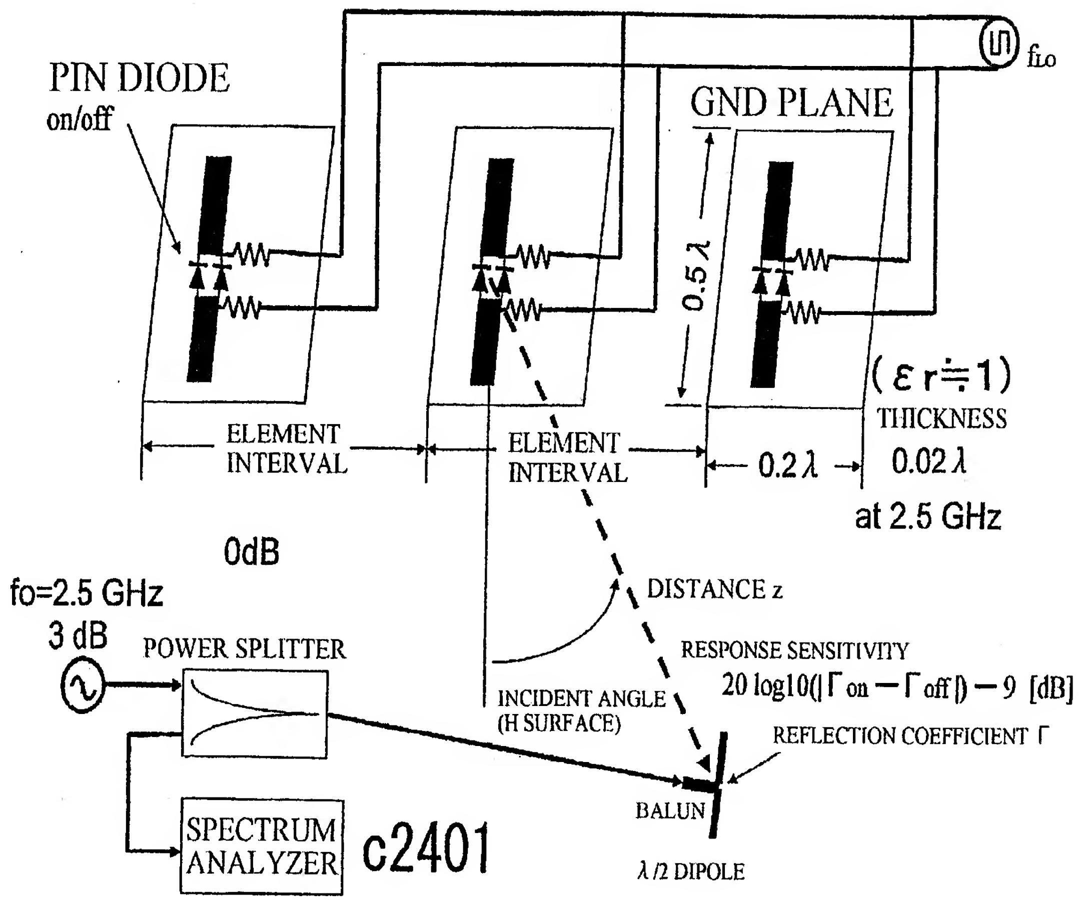

PIN DIODE
on/off
GND PLANE
fLo
0.5 λ
( ε r≒1)
THICKNESS
0.02 λ
at 2.5 GHz
ELEMENT INTERVAL
ELEMENT INTERVAL
0.2 λ
0dB
fo=2.5 GHz
3 dB
POWER SPLITTER
DISTANCE z
RESPONSE SENSITIVITY
20 log10(| Γ on − Γ off |) − 9 [dB]
INCIDENT ANGLE
(H SURFACE)
REFLECTION COEFFICIENT Γ
BALUN
λ/2 DIPOLE
SPECTRUM ANALYZER
c2401

FIG. 25

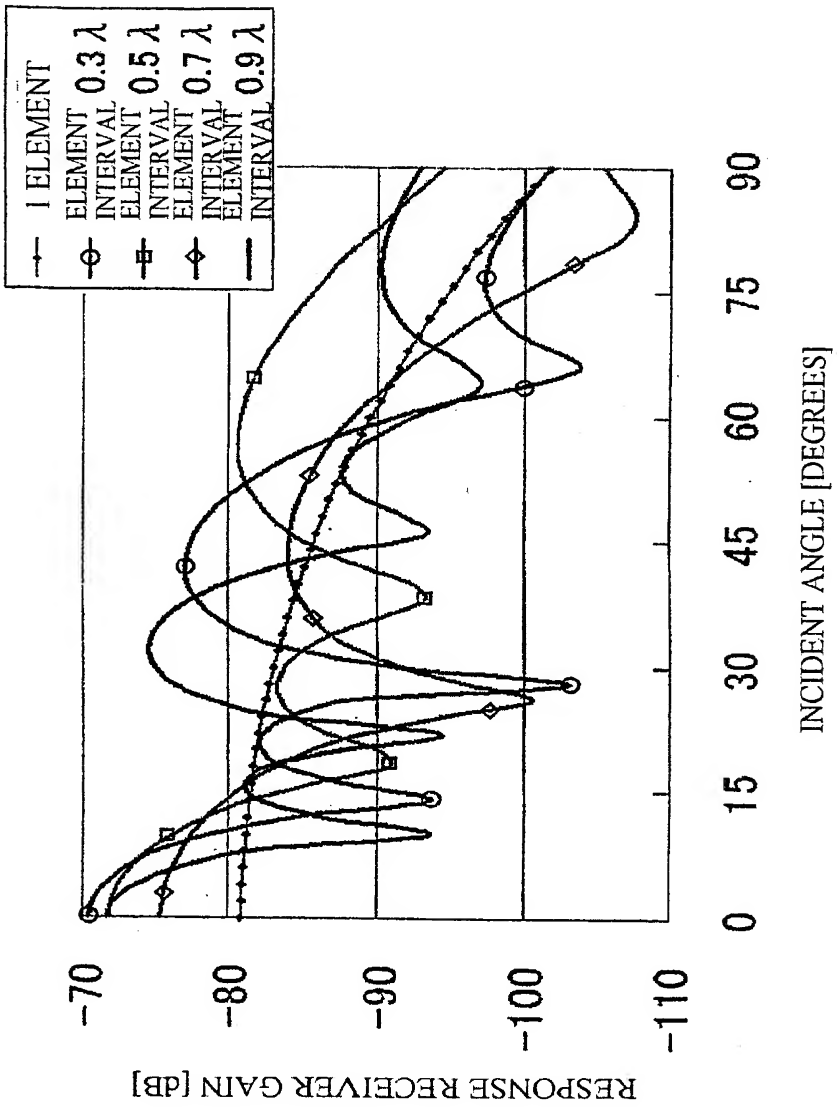

1 ELEMENT
ELEMENT INTERVAL 0.3 λ
ELEMENT INTERVAL 0.5 λ
ELEMENT INTERVAL 0.7 λ
ELEMENT INTERVAL 0.9 λ
−70
−80
−90
−100
−110
0
15
30
45
60
75
90
INCIDENT ANGLE [DEGREES]
RESPONSE RECEIVER GAIN [dB]

FIG. 26

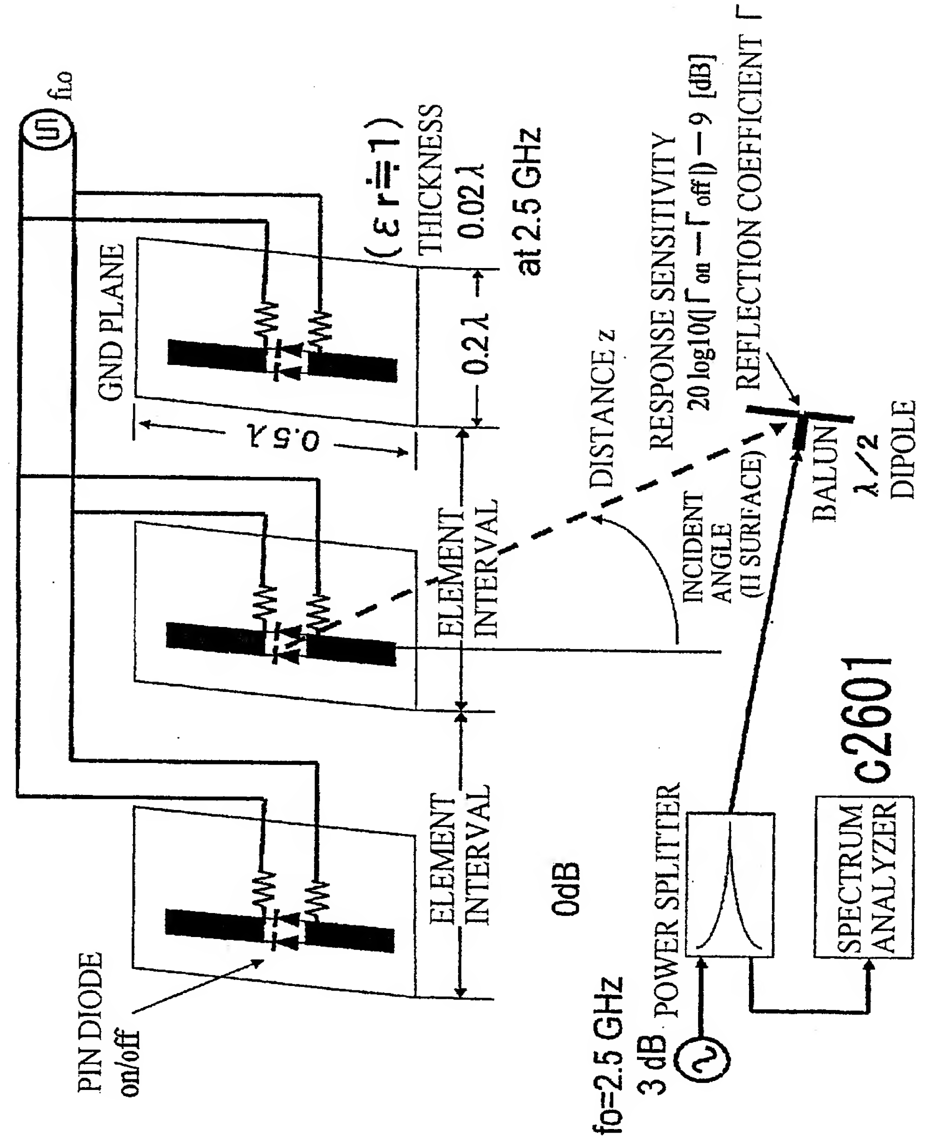

f_LO
GND PLANE
(ε r≒1)
THICKNESS
0.02λ
at 2.5 GHz
0.2λ
0.5λ
ELEMENT INTERVAL
ELEMENT INTERVAL
PIN DIODE on/off
0dB
DISTANCE z
RESPONSE SENSITIVITY
20 log10(|Γ on − Γ off|) − 9 [dB]
REFLECTION COEFFICIENT Γ
INCIDENT ANGLE (H SURFACE)
BALUN
λ/2 DIPOLE
fo=2.5 GHz
3 dB
POWER SPLITTER
SPECTRUM ANALYZER
c2601

FIG. 27

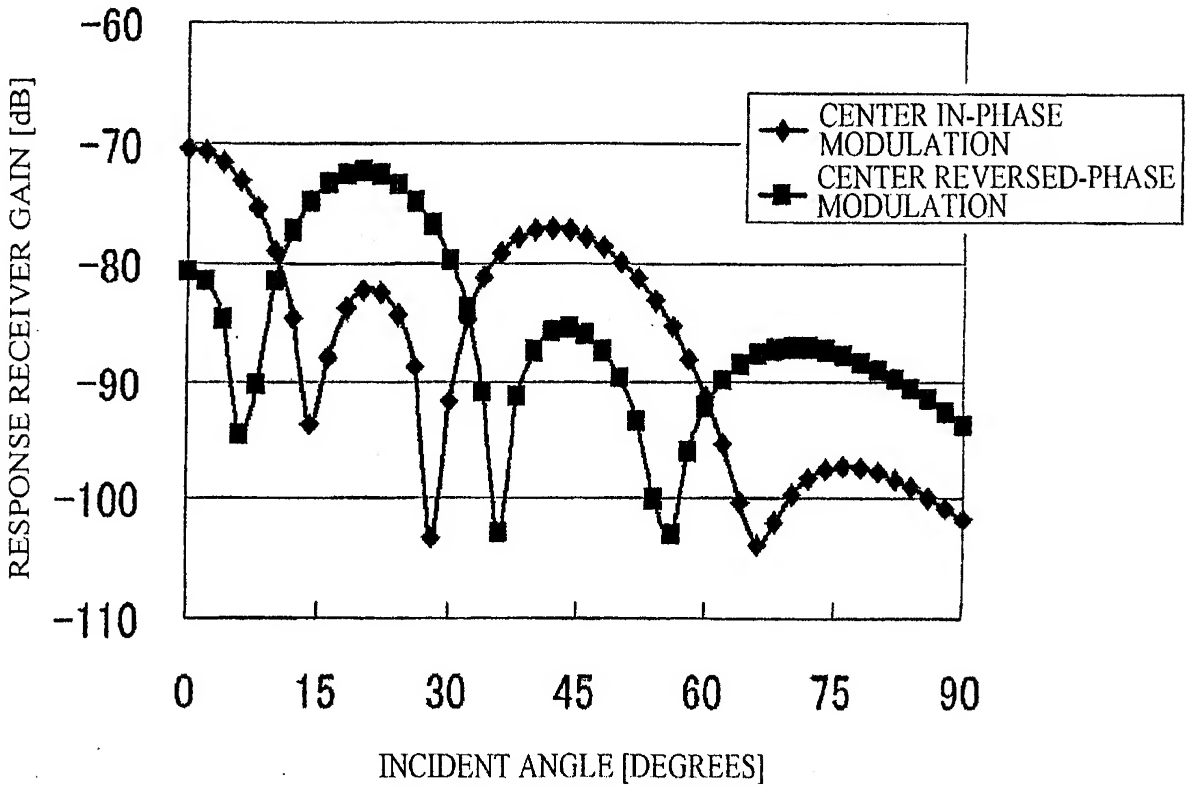

RESPONSE RECEIVER GAIN [dB]
-60
-70
-80
-90
-100
-110
0
15
30
45
60
75
90
INCIDENT ANGLE [DEGREES]
◆ CENTER IN-PHASE MODULATION
■ CENTER REVERSED-PHASE MODULATION

FIG. 28

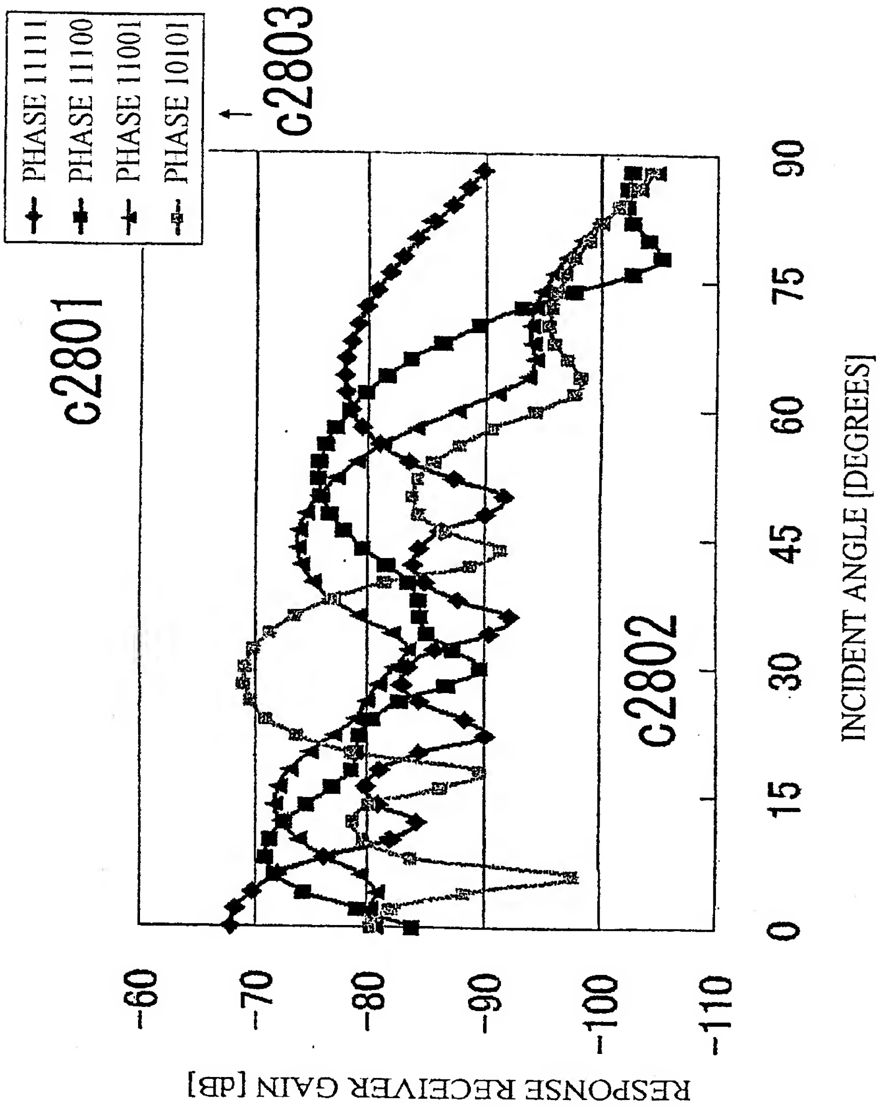
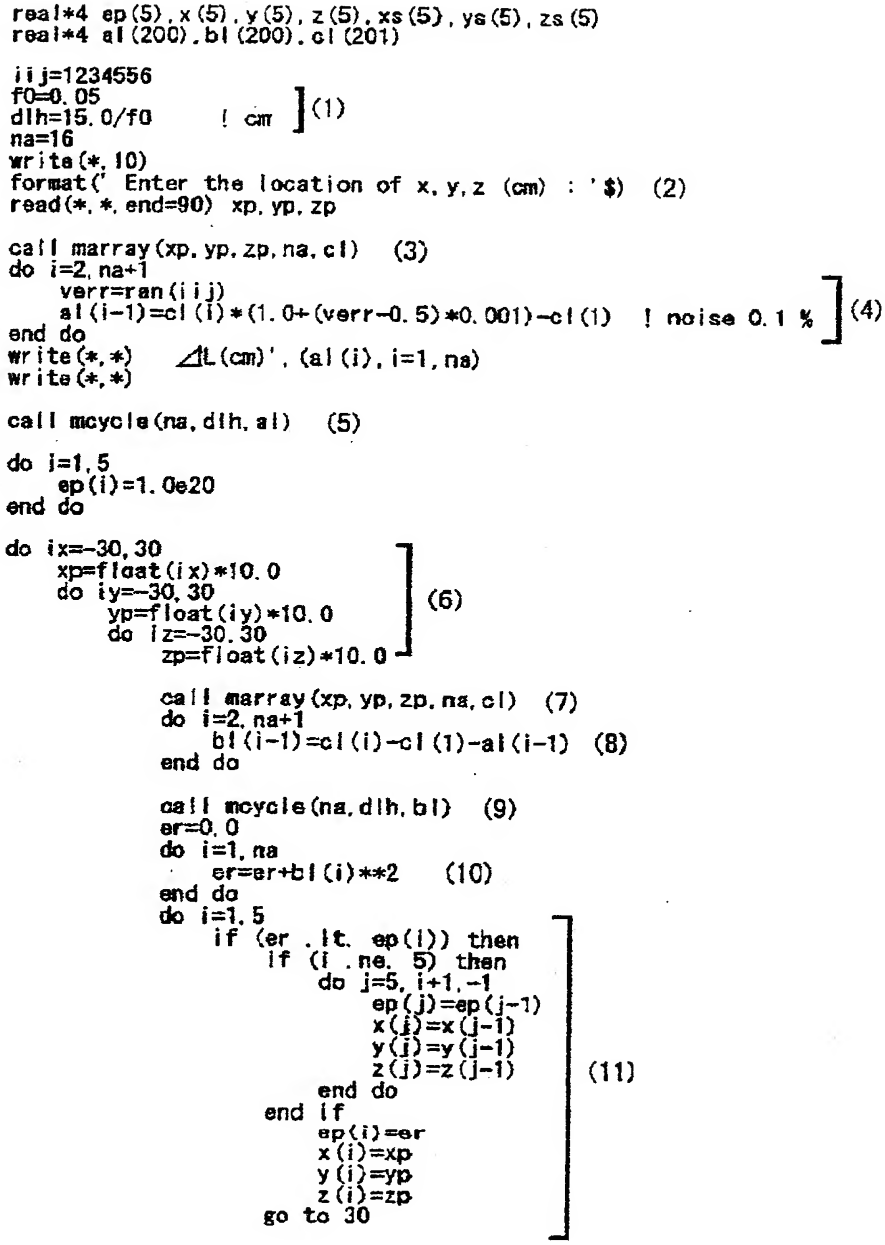

c2801
c2802
c2803
PHASE 11111
PHASE 11100
PHASE 11001
PHASE 10101
RESPONSE RECEIVER GAIN [dB]
-60
-70
-80
-90
-100
-110
INCIDENT ANGLE [DEGREES]
0
15
30
45
60
75
90

FIG.29



```
real*4 ep(5),x(5),y(5),z(5),xs(5),ys(5),zs(5)
real*4 al(200),bl(200),cl(201)

iij=1234556
f0=0.05                      ]
dlh=15.0/f0        ! cm      ](1)
na=16
write(*,10)
format(' Enter the location of x,y,z (cm) : '$)   (2)
read(*,*,end=90) xp,yp,zp

call marray(xp,yp,zp,na,cl)   (3)
do i=2,na+1
    verr=ran(iij)                                                  ]
    al(i-1)=cl(i)*(1.0+(verr-0.5)*0.001)-cl(1)   ! noise 0.1 %     ](4)
end do
write(*,*)   ⊿L(cm)', (al(i),i=1,na)
write(*,*)

call mcycle(na,dlh,al)   (5)

do i=1,5
    ep(i)=1.0e20
end do

do ix=-30,30                          ]
    xp=float(ix)*10.0                 ]
    do iy=-30,30                      ](6)
        yp=float(iy)*10.0             ]
        do iz=-30,30                  ]
            zp=float(iz)*10.0         ]

            call marray(xp,yp,zp,na,cl)   (7)
            do i=2,na+1
                bl(i-1)=cl(i)-cl(1)-al(i-1)   (8)
            end do

            call mcycle(na,dlh,bl)   (9)
            er=0.0
            do i=1,na
                er=er+bl(i)**2   (10)
            end do
            do i=1,5                                ]
                if (er .lt. ep(i)) then             ]
                    if (i .ne. 5) then              ]
                        do j=5,i+1,-1               ]
                            ep(j)=ep(j-1)           ]
                            x(j)=x(j-1)             ]
                            y(j)=y(j-1)             ](11)
                            z(j)=z(j-1)             ]
                        end do                      ]
                    end if                          ]
                        ep(i)=er                    ]
                        x(i)=xp                     ]
                        y(i)=yp                     ]
                        z(i)=zp                     ]
                    go to 30                        ]
```

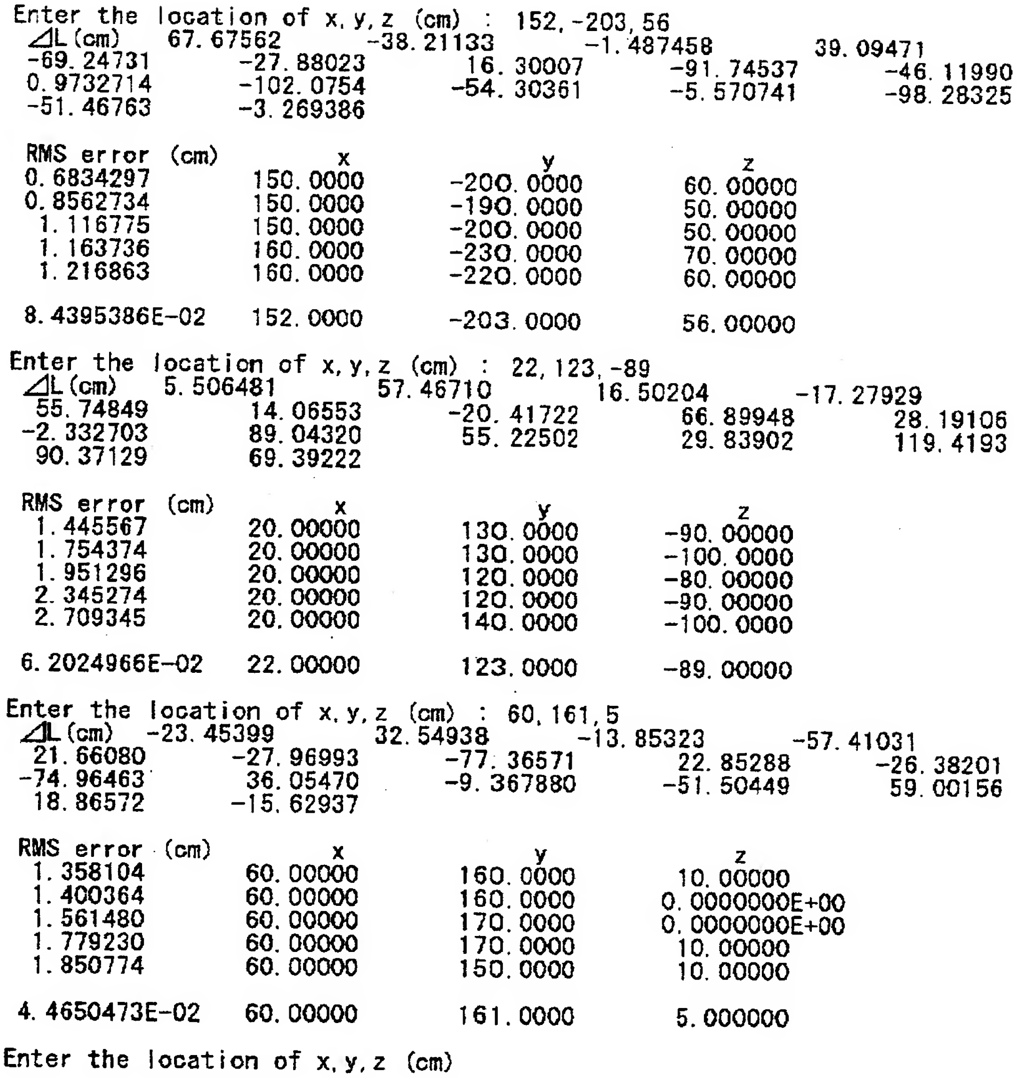
FIG.30

```
                end if
            end do
            continue
        end do
    end do
end do

do i=1,5
    xs(i)=x(i)
    ys(i)=y(i)
    zs(i)=z(i)
end do

write(*,*) ' RMS error (cm)          x               y                z    (12)
do i=1,5
    write(*,*) sqrt(ep(i)/float(na)),x(i),y(i),z(i)
end do

do m=1,5                                                                   (13)
    x0=xs(m)
    y0=ys(m)
    z0=zs(m)
do ix=-15,15
    xp=float(ix)+x0
    do iy=-15,15
        yp=float(iy)+y0
        do iz=-15,15
            zp=float(iz)+z0

            call marray(xp,yp,zp,na,cl)
            do i=2,na+1
                bl(i-1)=cl(i)-cl(1)-al(i-1)
            end do

            call mcycle(na,dlh,bl)
            er=0.0
            do i=1,na
                er=er+bl(i)**2
            end do

            do i=1,5
                if (er .lt. ep(i)) then
                    if (i .ne. 5) then
                        do j=5,i+1,-1
                            ep(j)=ep(j-1)
                            x(j)=x(j-1)
                            y(j)=y(j-1)
                            z(j)=z(j-1)
                        end do
                    end if
                        ep(i)=er
                        x(i)=xp
                        y(i)=yp
                        z(i)=zp
                    go to 35
                end if
            end do
```

FIG.31

```
            continue
        end do
    end do
end do

end do
write(*,*)
write(*,*) sqrt(ep(1)/float(na)),x(1),y(1),z(1)   (14)

write(*,*)
go to 20

stop
end

subroutine marray(xp,yp,zp,na,cl)

real*4 cl(1)

cl(1)=sqrt(xp*xp+yp*yp+(zp+50.0)**2)
do i=2,na+1
    ixx=i/3
    iyy=i-ixx*3
    xm=float(ixx-1)*50.0-10.0
    ym=float(iyy-1)*50.0+10.0
    cl(i)=sqrt((xp-xm)**2+(yp-ym)**2+zp*zp)
end do

return
end

subroutine mcycle(na,dlh,al)

real*4 al(1)

do i=1,na
    continue
    if (al(i) .gt. dlh) then
        al(i)=al(i)-dlh
        if (al(i) .le. dlh) go to 46
        go to 40
    end if
    continue
    if (al(i) .lt. -dlh) then
        al(i)=al(i)+dlh
        if (al(i) .ge. -dlh) go to 46
        go to 45
    end if
    continue
end do

return
end
```

FIG.32



```
Enter the location of x,y,z (cm) : 152,-203,56
 ⊿L(cm)    67.67562          -38.21133          -1.487458          39.09471
 -69.24731        -27.88023          16.30007          -91.74537          -46.11990
 0.9732714        -102.0754         -54.30361          -5.570741          -98.28325
 -51.46763        -3.269386

 RMS error  (cm)           x                 y                 z
 0.6834297        150.0000         -200.0000         60.00000
 0.8562734        150.0000         -190.0000         50.00000
  1.116775        150.0000         -200.0000         50.00000
  1.163736        160.0000         -230.0000         70.00000
  1.216863        160.0000         -220.0000         60.00000

 8.4395386E-02    152.0000         -203.0000         56.00000

Enter the location of x,y,z (cm) : 22,123,-89
 ⊿L(cm)    5.506481          57.46710          16.50204          -17.27929
  55.74849        14.06553          -20.41722          66.89948          28.19106
 -2.332703        89.04320           55.22502          29.83902          119.4193
  90.37129        69.39222

 RMS error  (cm)           x                 y                 z
  1.445567        20.00000          130.0000         -90.00000
  1.754374        20.00000          130.0000         -100.0000
  1.951296        20.00000          120.0000         -80.00000
  2.345274        20.00000          120.0000         -90.00000
  2.709345        20.00000          140.0000         -100.0000

 6.2024966E-02    22.00000          123.0000         -89.00000

Enter the location of x,y,z (cm) : 60,161,5
 ⊿L(cm)  -23.45399          32.54938          -13.85323          -57.41031
  21.66080        -27.96993          -77.36571          22.85288          -26.38201
 -74.96463         36.05470          -9.367880         -51.50449          59.00156
  18.86572        -15.62937

 RMS error  (cm)           x                 y                 z
  1.358104        60.00000          160.0000          10.00000
  1.400364        60.00000          160.0000         0.0000000E+00
  1.561480        60.00000          170.0000         0.0000000E+00
  1.779230        60.00000          170.0000          10.00000
  1.850774        60.00000          150.0000          10.00000

 4.4650473E-02    60.00000          161.0000          5.000000

Enter the location of x,y,z (cm)
```